A Shuttle Lesson Learned in Quality and its impact on Safety

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Agenda

- **Background**
- **Relationship Between process Control, Reliability, and System Risk - ET TPS Example**
- **TPS Process control**
- **TPS Reliability**
- **Impact of TPS failure on system risk using probabilistic engineering approach**
- **Conclusions**

Background

- In the past, space vehicle designers focused on performance and less on other system parameters
- Reliability and safety was covered by designing for high safety factors
- Safety factors are good if processes are in control and engineering analyses are bounding.
- Past experience has shown that even for the best design, engineering analyses are not bounding in cases of excessive process variability (lack of process control)

Background

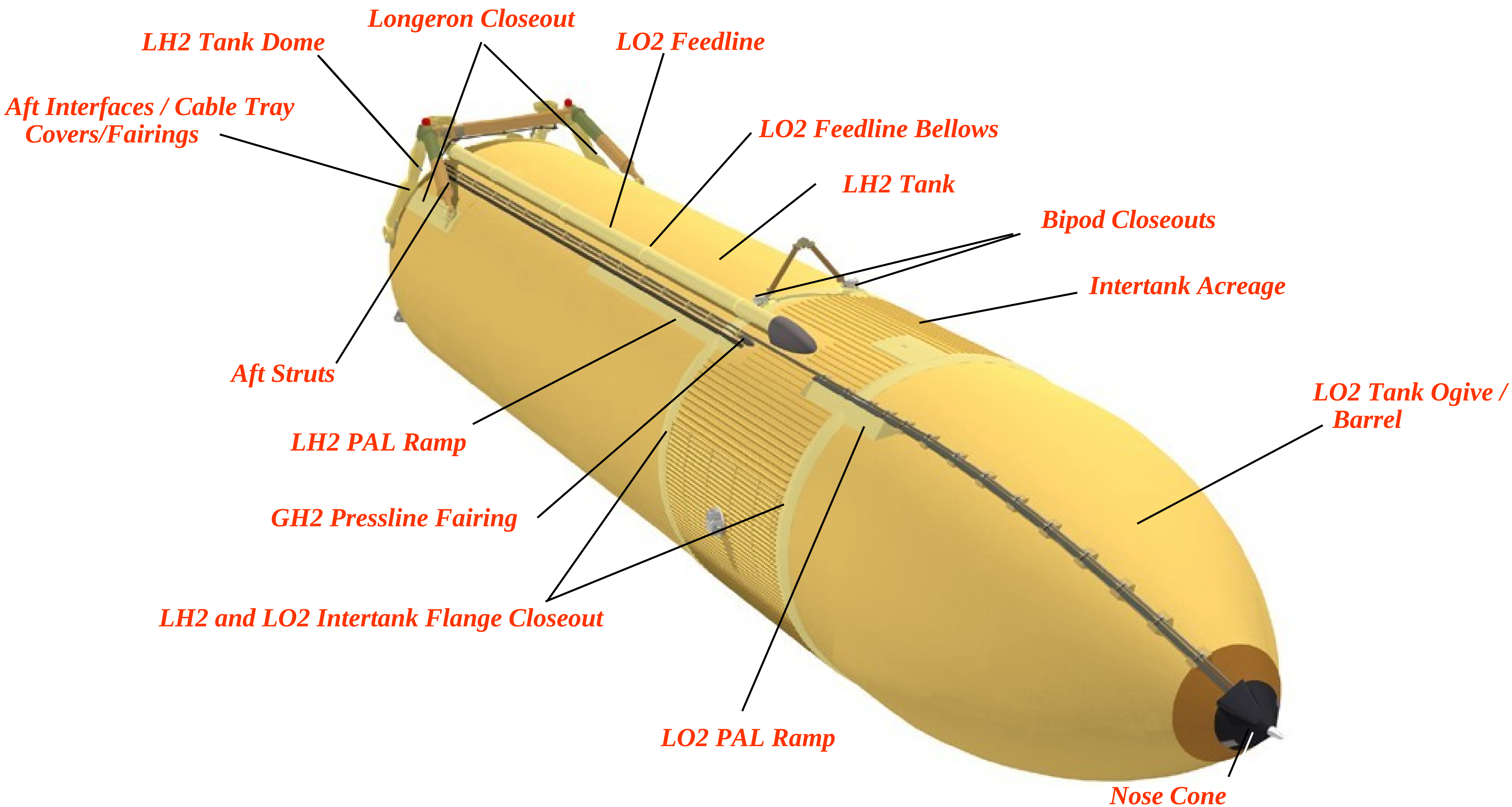
- Developing a safe and reliable space vehicle requires good design and good manufacturing, or in other words "design it right and build it right"
- Inadequate process control could result in low quality which leads to low reliability and high system risk
- The difficulties and sensitivities of the ET TPS manual spray process is a good demonstration of the impact of process control on component reliability and system risk

Background

The Shuttle External Tank (ET) Thermal Protection System (TPS)

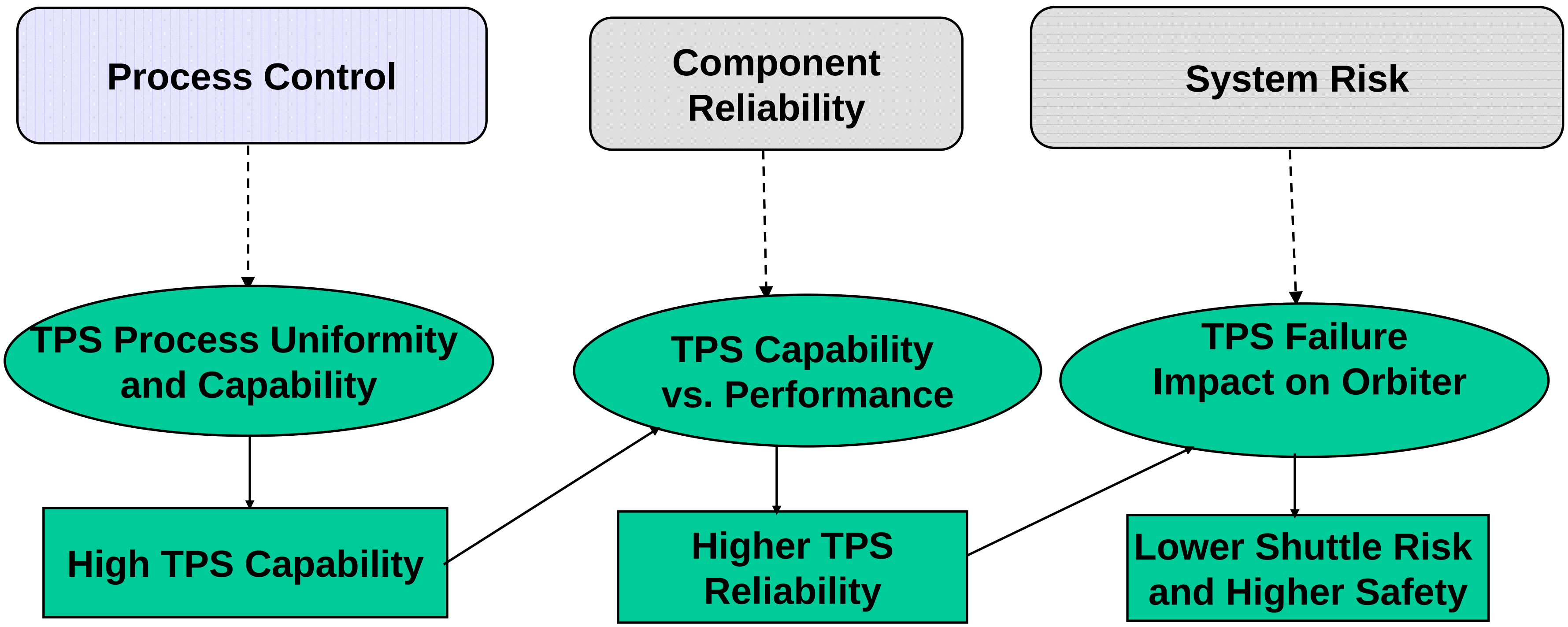
The TPS is applied to the ET to maintain cryogenic propellant quality, minimize ice/frost formation, and protect the structure from ascent, plume, and re-entry heating

Background
Thermal Protection System Overview



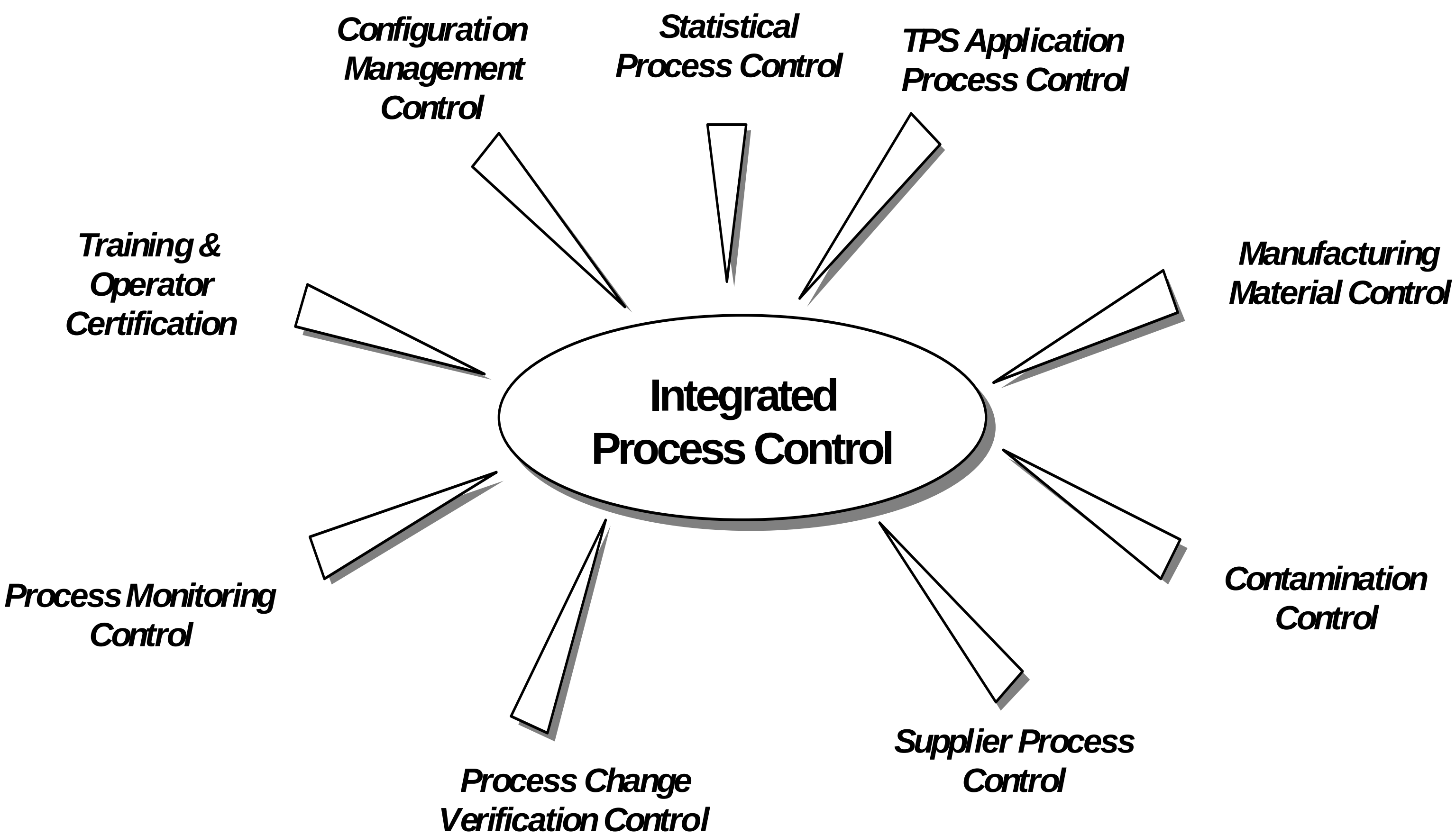
Relationship Between Shuttle process Control, Reliability, and System Risk ET TPS Example

Relationship Between process Control, Reliability, and System Risk



TPS Process control

ET TPS Integrated Process Control



Integrated process control (IPC) is critical to ensure consistent processes are employed for every part.

TPS Process control

Statistical Process Control

- A quality Engineering issue
- Statistical in nature
- TPS statistical data is extensive
- The output of process control is a uniform and capable process
- A critical input to the TPS reliability

Shuttle External Tank (ET) Return to Flight (RTF) Lessons learned

Process control for the Use-as-is foam

- Process variability was evaluated after the fact
- Dissection data collected after the Columbia accident showed excessive variability (Coefficient of variation is greater than 100%)
- Within tank variability was high, and tank to tank variability could not be fully characterized
- Defect/void characterization was difficult and statistics derived had high level of uncertainty
- The natural variation of the process was not well understood
- The relationship between process control variables and defects is not known
- For certification, a max expected void size was derived based on statistics and engineering analysis including a penalty factor for the unknowns in process control

TPS Process control

Process control for redesigned components and process enhanced foam

- Improved process/design
- Conducted verification and validation testing sufficient enough to understand and characterize the process variability and process capability
- Evaluated process pre-control charts for process readiness
- Evaluated process capability for meeting the specification
- Evaluated process control for process uniformity
- Statistical evaluation of the data showed that significant improvements were made in process uniformity and process capability, including significant reduction in the coefficient of variation (COV) of the process critical output parameters (e.g. void frequency and void sizes)

TPS Reliability

- The TPS reliability is defined in terms of TPS capability and system operating environment
- The TPS capability is driven by process uniformity, and process capability
- The process uniformity and process capability are characteristic of process defect frequency and defect size
- The output of reliability are probability distributions of divot frequency and divot size
- TPS reliability is a critical input to the probabilistic model for evaluating the impact of TPS failure on system risk

Impact of TPS failure on system risk using probabilistic engineering approach

Input Data | **Physics-Based Analysis** | **Validation Data**

ET TPS Dissections (ET Project)

TPS Void Statistical Distributions
Process Control

ET Dissection / Manufacturing Data

TPS Geometry, Properties, Boundary Conditions (ET Project)

TPS Debris Generation (divot/no divot, size/shape (mass), time and location of release, and pop-off velocity)
TPS Reliability

Thermal-Vacuum and Flight Imagery Data

Debris Transport and CFD Calculations (SE&I)

TPS Transport Model (axial/lateral locations and velocities during ascent)

Debris Transport Analysis

Orbiter Geometric Models (Orbiter Project)

Orbiter Impact Algorithms (impact/no impact, location, time, mass, velocity and angle)

Orbiter Post-Flight Data

Orbiter Impact / Damage Tolerances (Orbiter Project)

Orbiter Damage Analysis (tile/RCC panel damage)

Probability of Orbiter Damage Exceeding Damage Tolerance
System Risk

Conclusions

- Process control is a critical factor for achieving high reliability and low system risk
- Component designers of future launch vehicle should consider manufacturability and the feasibility of good process control in the design selection process
- An integrated process control plan should be developed upfront, and implemented throughout the different phases of the program